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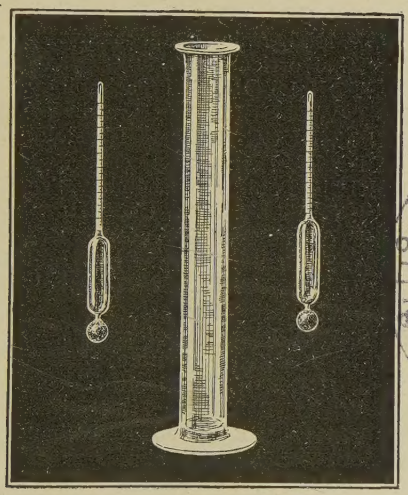
THE COLLEGE OF AGRICULTURE

Department of Plant Pathology

SPRAY INJURY INDUCED BY LIME-SULFUR PREPARATIONS



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By ERRETT WALLACE

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AUTHOR'S NOTE.

ITHACA, N. Y., *January* 23, 1910.

Director L. H. BAILEY, *College of Agriculture, Ithaca, N. Y.:*

DEAR SIR — In accordance with the terms of the Industrial Fellowship agreement with the Niagara Sprayer Company of Middleport, N. Y., I beg to submit herewith the third report of work with the recommendation that it be published as Bulletin 288.

The work has been done by Errett Wallace, Fellow, and represents investigations extending over the years 1909 and 1910. During the season of 1909, the work was performed in the orchards of L. B. Frear of Ithaca, N. Y., to whom we are indebted for liberal cooperation. In 1910, the experiments were located near Sodus, N. Y., and it is a pleasure to acknowledge the hearty cooperation of the fruit-growers of Sodus, especially B. J. Case, Henry Baxter, Daniel Legasee, Paulus Johnson, Mr. Darling, and Mr. DeWright, who allowed the use of their orchards and buildings for experimental purposes and very liberally aided the investigation in every way possible.

Due mention should be made of the fruit-growers of Wolcott, N. Y., who, largely through the instrumentality of Edward T. Brown, have cooperated very heartily. In 1909, some of the experiments on peach foliage were performed by D. H. Ayers, of Trumansburg, N. Y., who spared neither time nor trouble in promoting the work. Mr. Wallace was assisted in some of the field and laboratory work by F. M. Blodgett, Lex R. Hesler, P. J. Anderson, and W. H. Rankin.

Respectfully submitted,

(Signed) H. H. WHETZEL,

Professor of Plant Pathology.

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SPRAY INJURY INDUCED BY LIME-SULFUR PREPARATIONS

PRELIMINARY DISCUSSION

During the autumn and winter of 1909, there was considerable agitation concerning the use of lime-sulfur preparations as substitutes for bordeaux mixture in the control of fungous diseases of plants. On apples especially, during that and the previous season, results of experiments by Cordley ('10), Scott ('10), Beattie ('09), and Wallace ('10), indicated strongly that lime-sulfur solution properly used had certain advantages over bordeaux mixture. Although at that time we did not care to make positive recommendations or guarantee results, yet many growers ventured to use lime-sulfur solution as a summer spray the past season (1910). In connection with our own experiments, which were carried on at Sodus, N. Y., an attempt has been made to get together all the data possible on injury to fruit and foliage by both bordeaux and lime-sulfur preparations. While the majority of growers thus far seem well satisfied with the results, we have received occasional complaints of foliage injury and even of some fruit injury.

It is true that under certain conditions lime-sulfur solution used on apple foliage will cause quite objectionable and even serious injury. It is also true that it can be used in a way that will be effective without material injury. In our experimental spraying plats, lime-sulfur properly used controlled apple scab and the foliage remained as healthy as could be desired. There was some slight spotting which appeared soon after the applications and which the trees soon outgrew.

Messrs. Case, Baxter, and others in the vicinity of Sodus and in many other parts of the state, have sprayed their trees on a commercial scale, using lime-sulfur solution, with good results. Some, on the other hand, report serious injury. Why this difference in results? The writer has visited many of these orchards and believes that in most cases he has been able to locate with some certainty the cause or conditions favoring the injury. Some of the conclusions are based on circumstantial evidence and cannot yet be considered as demonstrated. On some points, indeed, we hardly dare draw conclusions and can only point out such

('09) Beattie, R. K. Western Fruit Grower, Jan. 1909:6–7.
('10) Cordley, A. B. Oregon Agr. Exp. Sta. Bul. 108:16. 1910.
('10) Scott, W. M. U. S. D. A., Bu. Pl. Ind. Cir. 54:3-15. 1910.
('10) Wallace, E. Western Fruit Grower, Jan. 1910:24–25.

evidence as is available. One thing is clear, foliage injury occurs much more abundantly at some times than at others. This is not a matter of chance. There are reasons for all things, although sometimes the reasons may be obscure.

TYPES OF INJURY

Before going further with our main topic, it is necessary to describe briefly some types of injury. Several types have been observed, varying mainly with the method of application and the condition of the leaf. Perhaps the most common type is the dull brown spotting or marginal and tip burning which occurs where hanging drops of the solution have gradually become more concentrated during the drying process. This is most likely to occur at the tips (Fig. 61) or margins of the leaves, where drops are most likely to form. In the case of spotting at or near the central part of the leaf, it will usually be noted on careful examination that previous injury by fungi or insects has made possible the entrance of the spray to the inner and more tender tissue (Fig. 62). This is often due to previous infection by the scab fungus, which in many cases can be seen as a black spot in the center of the dead, brown, quite sharply defined area burned by the spray. In cases in which the fungus has infected almost the entire leaf surface, which was a common occurrence this season, the whole leaf would be scorched to a crisp, leaving darker spots where the fungus was old and pronounced enough to be in evidence and showing only the spray injury where the scab was not yet noticeable.

In another type of injury which usually follows drenching of the foliage, large areas or entire leaves may be burned. In any case, the injury appears soon after the application, usually in three or four days. This indicates that it occurs while the spray is in the soluble form. It differs from bordeaux injury, which may not appear at all until several weeks have passed. Bordeaux injury may appear as very small spots which gradually enlarge, forming more or less subcircular or irregular brown areas, or the injured areas may be full sized at their first appearance (Crandall '09). The writer is convinced that in case of lime-sulfur injury the burned areas do not materially enlarge in size, at least for more than a very short time after their first appearance.

These points suggest a marked difference in the action of lime-sulfur solution and bordeaux mixture in causing the injury, which is readily explainable when the chemical properties of the two preparations are

('09) Crandall, C. S. Ill. Agr. Exp. Sta. Bul. 135:220-223. 1909.

borne in mind. In case of bordeaux, the copper, which is the active agent, is applied in the insoluble (hydroxide) form which is incapable of causing injury until in some way made soluble by atmospheric action, and possibly by other agencies such as leaf secretions, etc.* Therefore, the time of appearance and the extent of bordeaux injury is dependent on weather conditions. The agent active in causing lime-sulfur injury is doubtless the soluble sulfur in the form of a calcium sulfid and is applied as such. According to Haywood ('07), it remains in the soluble form but a short time. The injury then is very probably caused at once while the spray is drying and appears at its worst about one week after the application. This action is doubtless favored by the concentration of the solution as the drops dry out.

With these points in mind, we are in a position to consider the factors which may influence injury one way or another. This is the question of greatest economic importance, since the grower wishes to know how to use the spray effectively with the least possible injury to fruit and foliage. Theories have been advanced and conjectures made, some of which are supported by but slight evidence. It is true that many conflicting results have been obtained. Some cases apparently of unexplainable variation have occurred. Many have attributed the injury to the weather at the time of or after application. Knowing this to be the most important factor influencing bordeaux injury, it is quite natural that many should jump at this conclusion with reference to lime-sulfur.

After considering the principles of the action of lime-sulfur injury as compared with that of bordeaux, as stated above (p. 106), it is plain that we cannot draw conclusions concerning lime-sulfur injury from what we know about that caused by bordeaux. We are dealing with different chemicals in the two cases, whose properties are not at all similar. The problem is therefore a new one. We cannot generalize and study "spray injury." We must study lime-sulfur, bordeaux, arsenical injury, each individually. As a matter of fact, the discussion of this factor, later in the text (pp. 110–113), shows that we were unable from our experiments and observations to correlate weather conditions with lime-sulfur injury. Other factors, such as the method of application, the condition of the trees or foliage at or previous to the time of application, the arsenical

* For further consideration of this point the reader is referred to the following:
('96) Swingle, D. B. U. S. D. A., Div. Veg. Phys. & Path. Bul. 9:20. 1896.
('02) Clark, J. F. Bot. Gaz. 33:26–48. 1902.
('02) Bain, S. M. Tenn. Agr. Exp. Sta. Bul. Vol. XV, No. 2:42–53. 1902.
('04) Schander, R. Landwirtschaftliche Jahrbücher 33:462. 1904.
('07) Hedrick, U. P. N. Y. (Geneva) Agr. Exp. Sta. Bul. 287:148-151. 1907.
('09) Crandall, C. S. Ill. Agr. Exp. Sta. Bul. 135:200–296. 1909.
('07) Haywood, J. K. U. S. D. A., Bu. Chem. Bul. 101:18–21. 1907.

used with the lime-sulfur, etc., we believe to have much greater influence in this connection. A very important factor is the method of application. Drenching of the foliage is very likely to cause burning, though the solution used may be weak. It is also true that in case of leaves previously attacked by the scab fungus and probably injured by insect stings or bites, the spray is admitted to the interior of the leaf much more readily than to sound healthy leaves.

The question of combining arsenicals with the fungicide is of no less importance. Here again we cannot rely on our knowledge of the use of these poisons with bordeaux. The fact that arsenite of lime and paris green can safely be used with bordeaux is no criterion for their use with lime-sulfur. Certain quite complicated reactions occur when these substances are combined with lime-sulfur and the results are very different. Arsenate of lead is the only poison now known that can safely be used for this purpose. These and other factors which may or may not influence lime-sulfur injury are discussed at greater length in the following pages.

We have thus far considered only injury to apple foliage, since it constitutes the most important phase of our subject. Later in the text we shall also discuss briefly the possibility of injury to fruit of the apple and foliage of the peach (p. 128) and the pear (p. 127). If fruit injury by lime-sulfur is at all possible, it is at most of very minor importance as compared with that caused by bordeaux. Many cases of russeting attributed to lime-sulfur have been proved, by the presence of an equal amount of russeting on unsprayed trees in the same orchards, to be due to other causes, doubtless to certain weather conditions.

Peach foliage, as is well known, is much more tender than that of the apple. It is very easily injured, even by very dilute solutions of soluble sulfur. The difficult problem of a summer spray for peaches will probably be solved by some method of applying sulfur to the tree in an insoluble form. Good results have been obtained in Georgia by Scott and Ayres ('10), with self-boiled lime-sulfur. In our work at Sodus the past summer we were able to spray peach trees with commercial lime-sulfur solution diluted 1–30 by applying it with the carbonic acid gas sprayer, allowing the gas to stand in contact with the solution about one-half hour before starting to spray. This precipitated practically all the soluble sulfur and no foliage injury resulted from the use of lime-sulfur alone. When the trees were treated in this way with arsenate of lead added very severe arsenical injury resulted (see page 130).

('10) Scott, W. M. and Ayres, T. W. U. S. D. A., Bu. Pl. Ind. Bul. 174:1-31. 1910.

SPRAY INJURY RECORDED BY OTHER INVESTIGATORS

A. B. Cordley ('08) was the first to use lime-sulfur solution on a commercial scale as a summer spray for fungous diseases, although such a preparation is reported by Scribner ('86). On page 16 of Oregon Experiment Station Bulletin 108 Cordley ('10) states, "As a summer spray the results of the past three seasons' work at the Oregon Experiment Station prove conclusively that when properly diluted it (lime-sulfur) can be safely used upon apple, pear, plum and prune, potato, celery and other hardy plants and that it gives better results in controlling apple scab than does bordeaux, which has been the standard spray for this disease, and further that it does not produce the disastrous spray injury to the fruit which is so common and often serious when bordeaux is used." For apple scab Cordley recommends a dilution of 1–30 when the concentrate tests 32° Beaumé.

W. M. Scott of the United States Department of Agriculture, Washington, D. C., has also done much during the past three or four seasons to further our knowledge of the use of the various lime-sulfur preparations as summer sprays. He was the first to use the self-boiled preparation, which he has since demonstrated to be effective in the control of peach rot and scab, and when properly prepared to be perfectly harmless to the most tender foliage. This author ('09) reports having used factory-boiled lime-sulfur diluted 1–75 on peaches with serious results, and that even a dilution of 1–100 caused some injury. On cherry, 1–40 caused no injury. On apples, the first application of 1–20 scorched the young leaves badly, while 1–25 caused slight burning around the edges of the leaves. The fruit, however, was smooth, while the bordeaux russeted it quite badly. In Nebraska, on Winesaps, Scott used 6 ounces of paris green with 50 gallons of the lime-sulfur spray without any serious results. The following year, however, in Virginia the addition of paris green caused serious injury on all varieties except the Winesaps. Here lime-sulfur solution, diluted 1½ gallons to 50, and having added 2 pounds of arsenate of lead, caused but very slight injury, while a 2–50 dilution caused a small percentage of the foliage to drop. Scott also notes that lime-sulfur alone was more injurious than when arsenate of lead was added. In Michigan, the 2–50 dilution alone caused considerable injury after the second application, while the same concentration with lead arsenate caused no severe, although a rather

('86) Scribner, F. L. U. S. D. A., Bot. Div. Bul. 11:26–27. 1886.
('08) Cordley, A. B. Rural New Yorker, March 7, 1908:202.
('09) Scott, W. M. U. S. D. A., Bu. Pl. Ind. Cir. 27:7–15. 1909.
('10) Cordley, A. B. Oregon Agr. Exp. Sta. Bul. 108:16. 1910.

objectionable injury. In Arkansas, a 1–30 dilution with arsenate of lead showed no serious injury after the third application on June 2d, but after the fifth application injury increased rapidly (see p. 119). The addition of paris green proved disastrous, and that of arsenite of lime still more so. The self-boiled mixture caused no injury. Here, again, all lime-sulfur treated plats produced smooth and more highly colored fruit than bordeaux, which caused severe russeting and also considerable foliage injury.

Beattie ('09, '10) of Washington State reports no injury from a dilution, even as strong as 1–11, of the commercial preparation and an equivalent concentration of the home-boiled preparation. Waite ('10) reports on "Experiments on the Apple with some New and Little Known Fungicides," among which he includes several modifications of the self-boiled lime-sulfur. An "iron sulphid" preparation made by adding iron sulfate to the self-boiled mixture "was absolutely non-injurious to apple foliage," and he notes that the foliage on trees sprayed with this preparation "had particularly dark green color and held on later than any other leaves in the orchard. The twigs were stockier and the buds were finer and plumper than on any other plat." The fruit, however, he notes was slightly greener and a little later in ripening than on the other plats. A copper sulfid was prepared by adding copper sulfate to self-boiled lime-sulfur. This caused about one-sixth as much russeting of fruit as standard bordeaux, and very slight leaf injury. Another copper sulfid preparation was made by adding commercial lime-sulfur solution to bordeaux mixture. This caused quite severe leaf injury and somewhat more russeting of fruit than the copper sulfid spray made with the self-boiled mixture.

FACTORS THAT MAY OR MAY NOT INFLUENCE SPRAY INJURY

Climatic conditions

It is now generally known that certain climatic conditions favor bordeaux injury. We know that such injury is more likely to occur when the application of bordeaux is closely followed by rain. This fact may account in part for the prevalent opinion that the variation in results with lime-sulfur solutions is due largely to the weather conditions, either at the time of or after the application is made. We have not yet sufficient evidence to convince us that this is true. As to what influence the weather may have in this respect, we are uncertain. We are sure,

('09) Beattie, R. K. Western Fruit Grower, Jan. 1909:6–7.
('10) Beattie, R. K. Wash. Agr. Exp. Sta. Pop. Bul. 28:1–4. 1910.
('10) Waite, M. B. U. S. D. A., Bu. Pl. Ind. Cir. 58:3–18. 1910.

however, that other factors to be mentioned later in the text are of more importance in most cases of leaf injury. Some have thought that there is more injury when the application is made during wet weather or is followed by wet weather. There may be some evidence in favor of this opinion but it is not conclusive. Throughout the season a careful weather record has been kept and in the following table we have attempted to correlate the results of our experiments as to foliage injury, with these weather conditions. The table shows that no correlation could be established.

TABLE SHOWING WEATHER CONDITIONS AND SPRAY INJURY

APPLICATION	Date	Orchard	Day sprayed	1st day after	2d day after	3d day after	4th day after	5th day after	6th day after	Injury
No. 1*.....	Apr. 28	Legasee	clear...	rain .4	partly cloudy	showers .2	partly cloudy trace rain	rain .7	clear...	very slight
No. 1.....	Apr. 28	Baxter.	clear...	rain .4	partly cloudy	showers .2	partly cloudy trace rain	rain .7	clear...	very slight
No. 1.....	Apr. 29	Case...	rain .4	partly cloudy	showers .2	partly cloudy trace rain	rain .7	clear...	clear...	very slight
No. 1a.....	May 4	Legasee	clear...	clear...	clear...	clear...	trace rain	showers	partly cloudy showers (2 days)	very slight

*Application No. 1: Shortly before blossoms open; buds only fairly well exposed.
Application No. 1a: Immediately before blossoms open; buds well exposed; showing considerable pink.
Application No. 2: After blossom period, petals two-thirds fallen.
Application No. 3: About two weeks after No. 2.

In Applications Nos. 1, 1a, and 2, lime-sulfur solution testing 33.° Beaumé was diluted 1–30 with 2 pounds arsenate of lead added to 50 gallons.

In Application No. 3, the lime-sulfur was diluted 1–40 with the same amount of arsenate of lead.

Decimals refer to fractions of an inch rain-fall.

TABLE SHOWING WEATHER CONDITIONS AND SPRAY INJURY — *continued*

APPLICATION	Date	Orchard	Day sprayed	1st day after	2d day after	3d day after	4th day after	5th day after	6th day after	Injury
No. 1.....	May 5	Green..	clear...	clear...	clear...	trace rain	showers	partly cloudy showers .08, 2 das.	partly cloudy	slight
No. 2.....	May 20	Baxter.	rain .19	clear...	rain....	cloudy	rain....	rain .54 2 days	partly cloudy	very slight except one tree drenched
No. 2.....	May 25	Baxter.	showers .54 24th & 25th	partly cloudy	showers .09	clear...	rain....	rain.... .2	trace rain	very slight
No. 2.....	May 21	Case...	clear...	rain....	cloudy	rain....	showers .54 2 das.	partly cloudy	showers .09	slight injury
No. 2.....	May 23	Green..	cloudy	rain....	rain .54	partly cloudy	showers .09	clear...	rain....	severe injury; trees in poor vitality
No. 2.....	May 24	Legasee	rain....	showers .54, 2 das.	partly cloudy	showers .09	clear...	rain....	rain .2	almost no injury
No. 3.....	June 8	Case...	clear...	clear...	clear...	rain .38	partly cloudy	clear...	clear...	some injury but not serious
No. 3.....	June 8	Legasee	clear...	clear...	clear...	rain .38	partly cloudy	clear...	clear...	slight spotting, less than Case's same day
No. 3.....	June 13	Baxter.	clear...	clear...	clear...	partly cloudy	trace rain	clear...	clear...	almost no injury

A more detailed description of each case follows:

Application No. 1; just before blossoms opened

Mr. Legasee's orchard: Sprayed April 28th. Clear until 29th; then rain in the forenoon and afternoon, about .4 inches. May 1st, 2nd, 3rd, cloudy to partly cloudy and rain every day. Orchard in good vigor. Injury very slight. Hardly noticeable except on limbs very heavily drenched. Sprayed May 4th. Clear until the 8th; then trace of rain and cloudy with considerable showers 9th and 10th. Injury as above.

Mr. Case's orchard: Sprayed April 29th. Light showers and drizzly while spraying, not hard enough to wash off spray until dry. Rained harder in afternoon. Trees vigorous. No appreciable injury. Perhaps very slightly more than in Mr. Legasee's orchard,— occasionally a few spotted leaves. On bordeaux trees some leaves turned yellow and fell off after several weeks. Not serious.

Mr. Baxter's orchard: Sprayed same day as Legasee's; young trees, vigorous, sprayed with hand pump. Almost no injury.

Mr. Green's orchard: Sprayed May 5th. No rain until the 8th. Trace of rain on the 8th and cloudy. Quite steady showers on the 9th. Not heavy rain. Sprayed with hand pump. Trees in poor vitality, foliage not dark green as in other orchards. Slight spotting of foliage from this application.

Application No. 2; just after blossoms fell

Mr. Legasee's orchard: Sprayed May 24th in the forenoon. Rained about 4 P. M. and very heavy rain the following night and light misty showers next forenoon. Almost no injury, occasionally a spot burned.

Mr. Case's orchard: Sprayed May 21st. Some rain the night before; day clear and slight rain the 22nd, 23rd partly cloudy, and 24th and 25th considerable rain. Injury more conspicuous than on Mr. Baxter's or Mr. Legasee's trees.

Mr. Baxter's orchard: Sprayed May 20th. Day cloudy and rain about 6 P. M. Rained all evening and some in night. Light rain the 22nd. Practically no injury, very rarely a spot.

East of creek sprayed May 25th. Day cloudy, and drizzling showers in forenoon. Previous night, heavy rain. May 26th partly cloudy, 27th occasionally light showers. Very slight injury except on one tree that had not received application No. 1. This tree was drenched and was quite severely burned.

Mr. Green's orchard: Sprayed May 23rd. Cloudy, and a strong south wind. Rained quite heavily next day about 4 P. M. and was cloudy and

more or less showery the 24th, 25th, 27th, with rain again the evening and night following the 29th. Lime-sulfur applied with hand pump. Very serious burning; leaves of many branches were burned and brown in a week's time. Bordeaux and lime-sulfur were both applied the 25th. Slight drizzling rain while being applied. Lead arsenate and lime-sulfur precipitated by gas sprayer caused very little injury. At first, very rarely a spot, but later some yellowing of the leaves. At first, bordeaux injury did not appear but by June 21st about one-half of the foliage had turned yellow and much of it had dropped off. In case of bordeaux, the injury seemed to increase with time, while the lime-sulfur injury appeared at its worst about a week or so after the application and then the trees recovered gradually. Orchard uncultivated; trees in poor vitality.

Application No. 3; two weeks after blossoms fell

Mr. Legasee's orchard: Sprayed June 8th. Had rained considerable the 5th and 6th; clear and fine the 8th, 9th and 10th. There were heavy rains the night following the 10th and no more rain for several days. No noticeable injury. Slight spotting on a few limbs heavily drenched.

Mr. Case's orchard: Sprayed June 8th, same day as Mr. Legasee's. Foliage injury slightly more noticeable than in Legasee's orchard, but not serious.

Mr. Baxter's orchard: Sprayed June 13th. No rain until a trace on the 17th and 27th. Practically no injury except a slight amount on a few trees.

Mr. Green's orchard: The third application of lime-sulfur was omitted because of the severe injury from the second.

With this statement of facts, we should prefer that the reader draw his own conclusions. It seems that we are not able from these experiments to correlate with any degree of certainty foliage injury from lime-sulfur solution with any particular weather conditions. Practically the only case of severe injury occurred in the "Green" orchard. This was sprayed during fine weather with considerable rain following the next two or three days. We are inclined to attribute the injury in this case to the unhealthy condition of the trees and their lack of vigor to resist the caustic action of the spray. (See p. 127). A single tree in Mr. Baxter's orchard sprayed the 25th was quite badly burned, while the others in the same orchard sprayed the same day from the same tank of spray material were but slightly burned. This tree had not received the early application and was quite heavily drenched. (See p. 117).

The above table shows that in four cases rain occurred the same day the application was made, with injury varying from almost none to very slight. In five cases rain occurred the day following the application of the spray. In four of these the injury was but slight, while one plat, in which the trees were in very poor vigor, was severely injured. This seems to furnish *no evidence* in favor of the opinion so prevalent *that wet weather during or following the application of the spray very materially favors foliage injury.*

While our observations indicate strongly that weather conditions immediately following or at the time when the lime-sulfur solution is applied have no marked effect on the amount of foliage injury, it is quite probable that the weather conditions throughout the season previous to the time of spraying may have much influence in producing foliage that is susceptible or resistant to spray injury. We are convinced that apple foliage was in general more easily burned by lime-sulfur solution this season (1910) than last (1909). In the first place, the wet spring of 1910 was much more favorable for fungous infection, and this, doubtless, partly accounts for the greater spray injury this season. (See p. 123). According to Cordley ('09) it is possible that the weather conditions of the season affect the leaves physiologically to make them more or less resistant to injury. Cordley's data seem to us, however, to be open to another explanation. (See p. 126). Anything that influences the nutrition or growth of the tree influences the physiological condition of the leaves. The moisture supply, the mineral and plant food constituents available, the temperature, and many other factors may all have important influences in producing foliage that is able to resist the caustic action of a spray. Here the subject becomes complex, and we know almost nothing specific as to what influence each factor actually has. There is little wonder that unexplainable conflicting results are reported when we realize that the leaves of no two trees nor of the same tree in two seasons are alike morphologically or physiologically, and that we know almost nothing of these variations and the factors which induce them.

Concentration, and method of application

There is, of course, a limit to the concentration of lime-sulfur solution that can safely be used on foliage. This limit, however, is not so sharply defined as is often supposed. We cannot say that a concentrate testing 33° Beaumé, diluted 1–30, will cause burning of apple leaves and one diluted 1–40 will not. Other factors are really more important than

('09) Cordley, A. B. Better Fruit, April 1909:33–35.

this. We have sprayed acres of apple orchards with a 1–30 dilution without any serious injury. On the other hand, it is possible to cause burning with a much weaker solution. We are quite sure that most growers who have used lime-sulfur solution during the current season will agree that the method of application has much to do with results. If the nozzle is held long in one position and throws a coarse spray, drenching certain branches, there is likely to be injury whether the solution is strong or weak. A 1–50 solution applied in this way is more likely to burn than a 1–30 properly applied. The evidence of this is to be found in almost any orchard where certain limbs have been over-drenched. The solution collects in drops on the foliage and burns as the drops concentrate. Do not interpret this to mean that spraying should be less thoroughly done; we mean only that it should be more evenly distributed, coating so far as is possible every part but not over-drenching any part of the tree. The coating of spray should consist of very fine drops evenly distributed over the entire surface. If the application is too heavy, these drops coalesce to form large ones and dripping results. These large drops also collect at the tips and around the margins of the leaves, and as they dry the solution becomes more concentrated and burns (Fig. 61).

The proper distribution of the spray can best be obtained by using high pressure and a nozzle having a small hole. Some persons may consider it necessary to use a coarse spray to control the codling moth, but we have had almost perfect results in using a fine spray with high pressure. It is a common practice to use several nozzles on one rod. The number that should be used will depend on the size of the holes, the condition of the orchard as to crowding of trees, and the quickness of the operator. With too many nozzles in a crowded orchard where overarching branches interfere with free motion of the nozzle from one place to another, one is sure to over-spray certain branches. Much better work can be done by spraying with the wind from both sides of the tree. It is easier in this way to do a good job without over-spraying any part than by trying to spray both sides with the same wind. One should not, however, wait too long for favorable winds and thus miss getting the spray on at the right time, which is the most important factor in controlling the scab fungus.

Foliage tests made on a small scale are likely to be misleading, owing to the difference in the method of application. Last season (1909), preliminary to experiments on peach scab and rot, we made tests with a hand sprayer, spraying a few branches only with each preparation. Applied in this way, on a small scale, commercial lime-sulfur 1–50 or

even stronger seemed to cause but little injury. Later this same concentration was used, making a thorough application with a power sprayer. The results were very different. Applied in this way even a dilution of 1–100 caused quite severe injury, with about one-third to one-half defoliation.

Combining arsenicals with lime-sulfur preparations

Most arsenical compounds, when mixed with lime-sulfur, cause a chemical reaction, changing more or less both their own composition and that of some of the lime-sulfur solution. Some react rapidly, others more slowly. In some the reaction seems beneficial and in others injurious. Just what these reactions are is a problem for the chemist and will not be discussed here to any extent. We are interested here only in the result of the combination as to its effect in reducing or inducing foliage injury.

At present we know of but one arsenical that can be safely used with lime-sulfur solution on apple foliage and that is *arsenate of lead*. This has been used in this connection for the past three or four seasons with good results. In fact, reports and also our own experiments indicate that to some extent it neutralizes the caustic effect of lime-sulfur solution. Scott ('10) reports this to have been true, while paris green and arsenite of lime used with lime-sulfur solution caused serious injury. Paris green was used in his experiments in Virginia, Michigan, and Arkansas. He reports much more serious injury in every case where arsenate of lead was used. In Virginia and Michigan, lime-sulfur alone was used and caused decidedly more injury than the same concentration with arsenate of lead. In Arkansas, arsenite of lime was used with the result that the foliage was burned to a crisp after the first application. In these experiments, the injury from lime-sulfur and arsenate of lead seemed to be cumulative. After the third application, which was made June 2nd, no serious injury was apparent but it increased rapidly after the fifth spraying.

The cumulative nature of the injury and its continued occurrence for some time after the application rather suggests a similarity to the phenomenon noted in connection with our experiments on peach foliage described on page 130, in which case the burning was evidently due to arsenic injury. In this case, we notice that the weak lime-sulfur with arsenate of lead caused no injury to appear until more than a month after the trees were sprayed. At that time, a spotting and dropping of the foliage occurred which resembled in character that found much sooner on trees sprayed with arsenate of lead alone (p. 130, and Figs.

('10) Scott, W. M. U. S. D. A., Bu. Pl. Ind. Bul. 54:6–14. 1910.

65–67). Might it not be possible that under certain weather conditions sufficient arsenic would be thus liberated to injure apple foliage? If so, this would be a case in which arsenate of lead, though lessening the immediate injury caused by lime-sulfur solution, later caused arsenical injury. This, however, we believe would not often occur on apple foliage and perhaps only when a large number of applications are made. In our work this summer, pear trees sprayed with lime-sulfur solution alone, diluted 1–40, were burned decidedly worse than when arsenate of lead was added to the same concentration. On apples there was not enough burning in either case to show any marked difference.

Arsenite of lime (Stewart '09) was quite highly recommended last season on the basis that it is much cheaper than arsenate of lead, and theoretically it was expected to do as good or better work. It was tried this season on eight Baldwin trees in Mr. Case's orchard, being prepared and used according to prescribed directions. The first application was made April 30th before the blossoms opened. This caused no very serious injury but did cause decidedly more than the lime-sulfur solution and arsenate of lead on the adjacent row. The second application was given May 21st after the petals had fallen. The arsenite of lime scorched the foliage very seriously, causing the trees to lose about fifty per cent. of their leaves. The trees afterwards recuperated, however, and the fruit crop was good. The lime-sulfur with lead arsenate applied the same day caused almost no perceptible injury.

It may be possible that a safe method of preparing arsenite of lime for use with lime-sulfur solution can be developed, but with our present knowledge it is certainly unsafe to use any arsenical but lead arsenate for this purpose. In this connection we might add that our work during the past season both in the field and laboratory has proved that the addition of arsenate of lead greatly increases the fungicidal value of the lime-sulfur solution. Even though there were no insects to be controlled, it would seem advisable to add the arsenate of lead for use on pears and apples in order to increase the fungicidal properties of the lime-sulfur solution. Although the first cost of arsenate of lead is greater than other forms of arsenic, it is undoubtedly the thing to use with lime-sulfur as a summer spray. The slight difference in the cost of materials is not at all commensurate with the difference in results on the trees.

The character of the lead arsenate used may also be an important factor. Bradley ('10) reports that a much greater reaction takes place

('09) Stewart, J. P. Pa. State Exp. Sta. Bul. 92:18–19. 1909.
('10) Bradley, C. E. Jour. Ind. and Eng. Chem. 2:328. 1910.

between an acid lead arsenate and lime-sulfur than when the arsenate used is neutral; and that this greater reaction produces a larger amount of soluble arsenic. He also states that alkaline waters exert a soluble influence on arsenates, which is much more marked in case of acid arsenates. This opens up a possibility that the kind of water used in diluting the spray may in some cases be an important factor.

Effect of adding lime or sediment to lime-sulfur solution

We are often asked whether it is advisable to add lime to lime-sulfur solution. Will it prevent burning? Does the sediment remaining in the solution help to prevent burning?

We are not yet ready to give a positive answer to any of these questions. Some experiments were planned and carried out this season for the purpose of determining these points. In Mr. Case's orchard, one plat of several large Baldwin trees was sprayed with lime-sulfur solution, 1–30, with arsenate of lead and about 4 pounds of lime per 50 gallons added. The adjacent row was treated in the same way, omitting the lime. The amount of burning in either case was small, and we could notice no difference due to the addition of lime.

In Mr. Legasee's orchard, the Niagara brand heavy grade lime-sulfur solution containing sediment was compared with the clear solution, using a dilution of 1–30 in both plats. The injury in either case here was very slight. If any difference existed, we believe there was slightly more injury where the clear solution was used. This might be accounted for by the fact that the sediment, replacing a small quantity of the clear solution, would slightly reduce the percentage per volume of sulfids, to which the caustic properties of the solution are doubtless due.

Effect of precipitation by carbon dioxid on the lime-sulfur solution

Previous to the introduction of lime-sulfur as a spray material, the gas sprayer had gained considerable popularity. Now the question is often asked, "Can we use the gas sprayer to apply lime-sulfur solution?" This question arises because it is known that the carbonic acid gas which is used to furnish the power reacts with the soluble sulfids of lime-sulfur solution, throwing the sulfur into a comparatively insoluble form. The result is that a heavy white precipitate is formed in the case of lime-sulfur alone or a grey one when arsenate of lead has been added.

Since we believe it to be the soluble sulfur that causes the injury, we thought it might be possible to apply precipitated lime-sulfur on tender foliage and avoid all danger of injury. Our plan was to throw the ma-

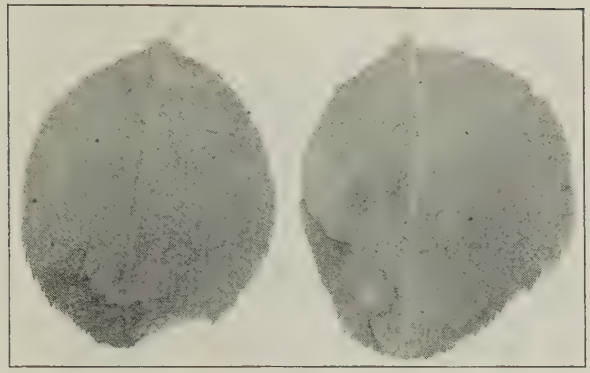

Fig. 61. *Showing type of injury on apple leaves that occurs where lime-sulfur solution collects around the margin or tips of the leaf (p. 106). Compare with Fig. 62, showing injury following scab infection.*

Fig. 62. *Showing lime-sulfur injury on apple leaves following scab infection. At a, the dark fungous growth can be seen in the center of the burned area. Note that the burned spots are distributed over the leaf wherever the scab spots had occurred, while in case of injury to healthy leaves the burning more often occurs where the spray collects and stands in drops, often around the margins or tips of leaves as in Fig. 61.*

Fig. 63. *Peach trees defoliated by spraying with lime-sulfur* 1-50 *and arsenate of lead, using gas sprayer. Compare with Fig.* 64, *sprayed with lime-sulfur* 1-30 *alone with gas sprayer.* (*See p.* 121.)

Fig. 64. *Peach trees sprayed with lime-sulfur alone diluted* 1-30 *and applied with gas sprayer. Compare with Fig.* 63, *sprayed in same way but with arsenate of lead added.* (*See p.* 122.)

Fig. 65. *Lime-sulfur injury. Leaves from tree sprayed heavily with lime-sulfur solution, 1-150, with arsenate of lead. Note that the type of injury differs from that caused by arsenic, Figs, 66 and 67.* (*See p. 130.*)

Fig. 66. *Peach leaves from tree sprayed with lime-sulfur, 1-30, with arsenate of lead precipitated by use of gas sprayer. Note that the type of injury is identical with the arsenical injury, Fig. 67, and unlike that caused by lime-sulfur, Fig. 65.* (*See p. 130.*)

Fig. 67. *Arsenical injury. Peach leaves from tree sprayed with arsenate of lead alone. Note that the type of injury is identical with that on those sprayed with lime-sulfur and arsenate of lead precipitated by the gas sprayer, Fig. 66, and decidedly different from lime-sulfur injury, Fig. 65.* (*See p. 130.*)

Fig. 68. *Showing fallen leaves under row of trees sprayed with arsenate of lead alone, 2 lbs. to 50 gals. Photographed a few days after application. Compare with Fig. 69, and read p. 130.*

Fig. 69. *Row of trees sprayed with lime-sulfur, 1–150, with 2 lbs, arsenate of lead to 50 gals., as it appeared about ten days after application, showing, when compared with Fig. 68, that the lime-sulfur delayed the arsenical injury. More than a month later, however, considerable injury also occurred on these trees.* (*Read p. 130.*)

terial into a comparatively insoluble form before application instead of applying the soluble sulfur and allowing it to become insoluble on the tree, which always happens in a very short time. (By this we do not mean that the final products are necessarily the same in both cases, but they are in both relatively insoluble and according to laboratory and field tests they seem to have about equal fungicidal value.) As previously stated, we believe it to be the soluble sulfur that causes leaf injury and if so it most likely occurs immediately after application, before the liquid dries on the tree. If this is true, we should entirely eliminate all lime-sulfur injury by precipitating the soluble sulfur before application.

This experiment was first tried on apples with apparently good results. Since the scab was well controlled, it was thought that we could make use of the same method to control peach rot and scab, thus avoiding danger of injuring the foliage. Accordingly, on June 14th peach trees were sprayed with lime-sulfur solution testing 34° Beaumé, diluted 1–30, and having added 2 pounds arsenate of lead to 50 gallons. The carbonic acid gas sprayer was used and the gas turned on about half an hour before starting to spray in order to insure as complete precipitation as possible. The mixture was kept well agitated while spraying. After about a week some considerable spotting and falling of leaves began to occur. In two weeks' time half the leaves had fallen from the Atlantas, and a considerable proportion from other varieties. The injury continued to increase until many of the branches were completely defoliated (Fig. 63).

This experiment was repeated in another orchard on June 22nd, using lime-sulfur, 1–50, with arsenate of lead. The result on Atlantas was the same as before. On the Yellow Elberg the injury did not appear until several days later than on the Atlantas, but was almost as severe in the end. The type of injury caused by lime-sulfur and arsenate of lead as precipitated by carbonic acid gas was quite different from that caused by lime-sulfur solution applied as such (Figs. 65, 66, 67). In case of the former, the burned spots have more of a reddish discoloration (Fig. 66).

This same type of injury was also found to occur but to a more limited extent where arsenate of lead alone was used (Fig. 67). (Compare Figs. 65, 66, 67). It therefore seemed probable that the injury was due not to lime-sulfur but to arsenic, in some way set free and made soluble by the action of the gas on the product resulting from the action between lime-sulfur solution and arsenate of lead. Chemists tell us that when lime-sulfur solutions and arsenate of lead are mixed, a reaction takes place which results in the formation of calcium arsenate. It is probable, there-

fore, that the carbonic acid gas acted on the calcium arsenate liberating arsenic in a soluble form.*

To confirm our conclusion that this was arsenical injury, a tree was sprayed heavily on July 6th with lime-sulfur solution 1–30, without any arsenate of lead, using the gas sprayer as before. In this case there was no appreciable injury (Fig. 64). The tree was sprayed the second time in the same manner, and two others with it. Again no injury occurred. The brown rot was reduced from 45 per cent. to 1½ per cent. by the two applications, and to 6½ per cent. by one application, showing that the precipitation destroying the caustic effect of the lime-sulfur for foliage did not destroy its fungicidal value. In case of apples sprayed with lime-sulfur solution and arsenate of lead with a gas sprayer, the leaf injury was not severe but after considerable time some leaves began to turn yellow and a slight dropping occurred.

Judging from these experiments, it would seem to be unsafe to use the gas sprayer when lime-sulfur solution and arsenate of lead are to be applied to foliage. On peaches the results would probably be serious, no matter how weak the lime-sulfur was used. On apples the result might not be serious but might be objectionable. The injury occurs more slowly but continues to develop much longer than that caused by lime-sulfur solution. Lime-sulfur solution alone, on the other hand, could be applied with the gas sprayer with much less danger of foliage injury than in any other way. It is probable that brown rot and scab of peach could be successfully controlled in this way without any foliage injury, provided we could obviate the necessity for using an arsenical with the fungicide to combat the curculio.

* Since writing the above, the chemical considerations here involved were presented to Professor Cavanaugh of the Department of Chemistry, who submitted it to Mr. C. C. Hedges, instructor in the same department, for investigation. Mr. Hedges submits the following report which confirms our conclusions that the injury is due to soluble arsenic set free through the instrumentality of the carbon dioxid:

"The injury caused by the lead arsenate alone was due, no doubt, to the soluble arsenic, and this soluble arsenic can be increased by passing carbon dioxid into the solution of lead arsenate.

"The lead arsenate used shows .36 per cent of water soluble arsenic oxid (As_2O_5). In a water solution saturated with carbon dioxid, the lead arsenate solution shows .44 per cent. of soluble arsenic oxid."

With reference to the injury caused by applying lime-sulfur solution combined with lead arsenate precipitated by carbon dioxid, Mr. Hedges states:

"This injury, I think, is caused by the action of the carbon dioxid on the lime-sulfur solution forming calcium carbonate and some hydrogen sulfid. The hydrogen sulfid reacts with the lead arsenate forming lead sulfid (the black precipitate) and some soluble arsenic. Some soluble arsenic may also be produced by the action of the carbon dioxid on the calcium arsenate that is produced by the reaction of the lime-sulfur and lead arsenate.

"The lead arsenate and lime-sulfur solution after being saturated with carbon dioxid shows .66 per cent. of soluble arsenic oxid."

Effect of apple scab infections previous to time of application, and of injury by insects

After a careful examination of a large number of apple orchards, we have no doubt that a large percentage of the serious cases of foliage injury this season has been due to the fact that the leaves had been attacked by the scab fungus before the spray was applied. Many growers have noticed that the later applications have caused the most injury, and that the older leaves were burned worse than the younger ones. Why so? The scab fungus had developed more on the older leaves because they had been exposed to infection earlier. In many cases these older leaves are found to be spotted or even coated with a growth of the scab fungus. In its early stage this is commonly overlooked, as the fungus is rather inconspicuous, appearing at first only as a very indistinct olive-green, velvety discoloration, turning brown later. Although inconspicuous, it is there and has destroyed the protective cuticle of the leaf. This permits free access of the spray material to the inner and more tender tissues, and burning results (Fig. 62).

In this connection it might also be noted that this year many observers have noticed that the leaves from fruit buds were most severely injured. Many have also noticed that in unsprayed orchards these leaves are more scabby than are those from leaf buds. We are convinced that these leaves are more scabby because they were the first leaves to open in the spring and were thus earlier exposed to fungous infection for which the early spring weather the past season was most favorable. This explains, then, why such leaves were most injured by the spray mixture.

It has also been noted that the application of bordeaux mixture following scab infection causes a similar injury. In the spring of 1909, a case of serious leaf injury on apples was reported to Professor Whetzel ('10) from Medina, N. Y. Accordingly, the author of this bulletin was sent to investigate the case. The foliage was burned so severely that the trees from a distance appeared brown and blighted, many of the leaves spotted, others scorched to a crisp. A microscopic examination of the burned spots revealed the fact that in practically every case the fungus had been present before the spraying was done. Hundreds of spots were examined, and spores of *Venturia inaequalis,* the scab fungus, could be found almost universally present. The orchard had not received the application just before the blossoms opened, thus permitting this early infection to take place. The infection was much favored also by the fact that an abundance of the winter stage of this fungus had de-

('10) Whetzel, H. H. Proc. N. Y. State Fruit Growers' Assn. 9:19–20. 1910.

veloped on the dead leaves which had not been plowed under early in the spring.

Shortly after this, there came to our attention Bulletin 135 of the Illinois Experiment Station, by C. S. Crandall ('09), in which the author notes that minor insect injuries and fungous infections, by breaking the leaf cuticle, favor bordeaux injury. He also notes that minor injuries are much more abundant than commonly supposed and that critical examination of 6,000 leaves, taken at random from 60 different trees, showed only 27 or less than ½ per cent. of absolutely perfect leaves, although the general appearance of the foliage on these trees was good. On page 231 of the same bulletin, reference is made to the work of Schander ('04), who found that leaves of apple, grape and pear whose epidermis had not been broken were not injured by a 1–100,000 copper sulfate solution, while leaves whose surface had been pricked with a needle were considerably injured. He concluded that the epidermis of these leaves is capable of preventing the penetration of copper compounds, but that the copper having once penetrated, behaves towards the protoplasm of the leaf cells in the same manner as towards the cells of algae and fungi, and in very dilute solutions can injure the protoplasm. It is very probable that this same explanation will hold good for soluble sulfur. The matter of physical injuries by fungi and insects as influencing spray injury is doubtless one of much importance and opens up an interesting field for study.

Many specific instances confirming our conclusions on this point might be cited. One or two, however, is all that space will permit. Mr. Edward T. Brown, of Wolcott, N. Y., during the spring of 1910 sprayed the larger part of his orchard twice, giving the first application just before the blossoms opened, and using lime-sulfur solution diluted 1–30 with arsenate of lead added. On a young orchard adjoining, this application was omitted. Both orchards were sprayed after the blossoms fell. In the case of the young trees, the foliage was severely burned, while on those which had received the spraying just before the blossoms opened to prevent early fungous infection, no material injury resulted. Further to convince ourselves that the spray injury was due to previous fungous infection, burned leaves were examined and the scab fungus could be seen even with the naked eye in almost every burned spot.

A case of quite serious foliage injury was reported by F. M. Wooster, of Lake Side, N. Y. We were not able to visit this orchard personally, but Professor F. C. Stewart ('10) of the Geneva Experiment Station

('04) Schander, R. Landwirtschaftliche Jahrbücher 33:544. 1904.
('09) Crandall, C. S. Ill. Agr. Exp. Sta. Bul. 135:221–222, 233. 1909.
('10) Stewart, F. C. Reported by letter to Professor Whetzel.

inspected it and reports that the injury was probably due to previous fungous infection. The injured leaves were abundantly infested with scab and no other satisfactory explanation of the injury could be found.

It is also evident that there is much more foliage injury when the spring and early summer months are wet. This is noticeable in comparing our results in 1909 with those in 1910. In 1909, on Greening trees even when heavily drenched, lime-sulfur diluted 1–30 with lead arsenate added, caused no injury. This season, when as heavily applied, the same spray caused quite noticeable burning. A similar instance was noted by C. B. Shafer, of Middleport, N. Y. Mr. Shafer had sprayed very heavily with lime-sulfur and lead arsenate in 1909 without any injury. In 1910, a similar application caused considerable injury. We are convinced that the difference in both cases is due largely to the fact that the wet season of 1910 was so much more favorable to fungous infection. In fact, we could easily tell by examination of the burned leaves, especially in Mr. Shafer's orchard, that the scab fungus had been present quite abundantly before the application was made.

It should be noted in this connection, however, that scab infection alone may not be entirely responsible for this unusual amount of burning. It is also possible that a cold, wet spring may affect the leaf physiologically to make it more easily injured, as held by Cordley ('09). The following paragraphs are quoted from Cordley's article.

"Our own experience, however, showed conclusively that the same trees which in 1907 were sprayed with 1 to 15 without injury, were seriously injured when sprayed with a spray of exactly the same strength in 1908. This apparent anomaly can, I believe, be accounted for by the different climatic conditions of the two seasons. From April 15 to May 17, during which period all of the spraying was done in 1907, but .73 inches of rain fell, and the minimum temperature fell as low as 32° upon only one night. In 1908, during the same time, 4.1 inches fell. The minimum temperature reached 30° upon one night and upon two successive nights, May 8th and 9th, touched 32°. It seems quite apparent, therefore, that the abundant sunshine and milder temperature of 1907 produced a vigorous, hardy, spray-resisting growth of foliage, while the excessive rainfall and cloudy weather and low temperature of 1908 produced a growth which was less vigorous, less hardy and more edematious and more susceptible to spray injury."

"The first spraying [1907] was given April 20, just as the blossoms were beginning to show color; the second application was made May 8, just after the petals had fallen; and the third was made May 18. In

('09) Cordley, A. B. Better Fruit, April 1909:33–35.

1908 the orchard was again sprayed for San José scale in February. For the purpose of testing the value, if any, of late winter applications for scab, the orchard was again sprayed April 4, just before the buds started, and no more applications were made until after the blossoms fell May 9 to 23, and the last one was made June 6 to 8."

From the above data it would seem that Cordley's results may be open to another explanation. It will be noted that the weather conditions in 1908 in Oregon ("excessive rainfall, cloudy weather, and low temperature") were much more favorable to scab infection than in 1907 ("abundant sunshine and milder temperature"); also, that in 1907 an application of lime-sulfur was made *just before* the blossoms opened as well as after they had fallen, while in 1908, the application just before the blossoms opened *was omitted*. This omission, as shown by our observation of many cases, has usually resulted in abundant early scab infection of the leaves, which became responsible for an increased amount of foliage injury when the spray was applied after the blossoms had fallen. May not scab infection, therefore, rather than lowered vitality due to the weather, have been the controlling factor in the injury reported by Cordley for the season of 1908?

H. A. Aldrich ('09) reports a case of burning which could be explained on the same basis. He states that, "After a little over half of this orchard had been sprayed, we noticed a slight burn where we had used the Rex, but none where we had used the Niagara. Thinking there was a little too much burn, and the *scab showing up all over the orchard,* we changed to bordeaux, but only used the 2–4–50 mixture with the result of the worst burn we ever experienced or ever saw in any other orchard." Mr. Aldrich further says, "Now this burn has proved a considerable of a mystery. Thorough investigation failed to find a thing wrong with any of the materials of which that spray was composed and every hand on the job was ready to swear that the right quantities were used. It is true that for those same two days the atmosphere had that peculiar condition where everything burns." In this case, according to Mr. Aldrich's own statement, the scab fungus was showing up abundantly in the orchard when the spraying was being done, and since we know this to be capable of inducing such injury we have little doubt that this, partly, if not completely, explains the phenomenon. It is also probable that the wet weather following the application may also have increased the caustic action of the bordeaux mixture. This may also account for the fact that the bordeaux in this case caused more burning than did the lime-sulfur, since the weather conditions that induce bordeaux injury do not induce injury by lime-sulfur.

('09) Aldrich, H. A. Western Fruit Grower, Feb. 1909:114.

Health and vigor of tree

Experiments on foliage during the past season seem to indicate that the health and vigor of the tree and the consequent condition of the foliage as influenced by care and cultivation or other conditions, may affect the susceptibility of the foliage to spray injury. Three of the apple orchards in which we worked were well cultivated and the trees were vigorous, while the fourth had been uncultivated and poorly nourished for years. The foliage did not have the dark green healthy color the others had. In this orchard the 1–30 lime-sulfur with lead arsenate scorched the foliage quite badly, while no serious injury occurred in any of the other orchards.

A similar result was noticed on pear trees due to devitalization of the trees by fire blight. A Bartlett orchard sprayed with lime-sulfur 1–50 with arsenate of lead showed almost no burning of foliage, except on a single tree that had been attacked by blight canker in the trunk that cut off the food supply, with the result that the foliage was off color and not vigorous. There was quite severe burning on this tree.

We would not attempt to go further than to suggest what might be an explanation of these phenomena. It would seem that the weakened vitality was probably an important factor, although the matter of parasitic injuries by insects and fungi may also have influenced results. There is no doubt but that there were more insects in the uncultivated apple orchard, although there did not appear to be any more scab present than in some of the others.

We have already referred (p. 125) to the possibility of the variation on the same trees in different seasons being partially due to the physiological condition of the leaves induced by weather conditions, and pointed out that this may also be largely explained by the fact that those weather conditions also affect the prevalence of injuries by parasites.

Varietal susceptibility

In the case of pears, the Duchess was found to have foliage much more tender than any other variety under observation. Clairgeau, Bartlett and Seckel alternating with the Duchess, showed but slight injury from lime-sulfur, while the Duchess trees were injured considerably, losing perhaps 20 per cent. of their foliage. In Mr. Case's orchard, many varieties were sprayed with lime-sulfur 1–50, with arsenate of lead 2 pounds to 50 gallons. Slight injury was perceptible on all varieties, but much more on the Duchess. Among other varieties there was no marked difference.

In case of apple foliage, very little that can safely be attributed to varietal susceptibility has been noted on the varieties under observation

in our experiments. W. M. Scott ('10) notes that the Winesap is much more resistant to spray injury than other varieties.

Concerning fruit injury by lime-sulfur solution, we know very little as yet. If any russeting has been caused by lime-sulfur it is so little more evident than the natural russeting that has occurred quite commonly this season that it is very hard to distinguish between the two, and therefore impossible to draw conclusions concerning varietal susceptibility. (See p. 135).

In the case of peaches, we sprayed Crawfords, Elbertas, Atlantas, Early St. Johns, and Yellow Elbergs. The foliage of the Atlantas seemed to be more tender than any other. No marked difference between the others was detected.

SPRAY INJURY ON PEACH FOLIAGE

As most growers already know, the foliage of the peach is extremely tender. It has long been a problem to find a spray that can be used effectively without serious burning. Some have tried bordeaux with very serious results. Others, presumably under very favorable weather conditions, have used it with some success in certain cases. The practice, however, is generally admitted to be unsafe. Up to the present date the only fungicide that has been demonstrated beyond doubt to be safe and effective for use on peach foliage is the self-boiled lime-sulfur devised by Scott ('08 and '10) of the United States Department of Agriculture, Washington, D. C. When properly prepared, this seems to be perfectly harmless to foliage and effective against the scab and brown rot. In our experiments, various modifications of lime-sulfur solutions have been tried.

In general, lime-sulfur solution, unless applied very weak, is likely to cause considerable burning of peach foliage. The occurrence and character of the injury is quite different from that on apple foliage. In the latter case, the dark brown spots or burned areas at the tip or margin of the leaf (Figs. 61 and 62) appear within about two days after the application. On peach leaves it may be almost a week before the spotting is noticeable. Then, certain definitely outlined spots appear usually rather pale green, with darker green or sometimes reddish brown borders. In mild cases it somewhat resembles the effect of the leaf spot fungus; and as in case of leaf spot, the injured part finally drops out leaving the shot hole effect (Fig. 65). As on apple leaves, this injury is most likely to occur where drops of the solution have concen-

('08) Scott, W. M. and Ayres, T. W. U. S. D. A., Bu. Pl. Ind. Cir. 1:1–18. 1909.
('10) Scott, W. M. and Ayres, T. W. U. S. D. A., Bu. Pl. Ind. Bul. 174:1–31. 1910.
('10) Scott, W. M. U. S. D. A., Bu. Pl. Ind. Cir. 54:7. 1910.

trated. Very slight injury is sufficient to cause the falling of peach leaves, so that defoliation in severe cases is likely to be very noticeable.

During the summer of 1909, a series of experiments were carried out to determine what concentration of lime-sulfur solution could be used on peach foliage and whether or not this concentration would be effective. These experiments seemed to indicate that much depends on the method of application, a point which has already been discussed with reference to apple foliage (p. 116). Preliminary tests were made, using a hand pump and spraying a few limbs with each concentration. In these tests a dilution of 1–50* or even stronger caused but very little injury.

When we applied this same concentration, using a power sprayer, and making a rather heavy application, there was serious defoliation. Even 1–100 heavily applied in this way caused about one-third to one-half defoliation. Where 1–150 was used there was some spotting, but the injury was slight; and a dilution of 1–200 caused no noticeable injury. No arsenical was used with the lime-sulfur in any of these experiments. The following report of work done by Mr. D. H. Ayers of Trumansburg, N. Y., shows that he was able to use much greater concentrations without injury than above indicated. The difference is probably due largely to the method of application. In our tests in 1909 the spray was quite heavily applied and with a coarser nozzle than that used by Mr. Ayers.

Experiments on peach foliage at Trumansburg, N. Y., in 1909, by D. H. Ayers

Extensive experiments were carried out by Mr. Ayers to determine what concentration of lime-sulfur can be used safely on peach foliage, and if possible to find a concentration both safe and effective.

The plats were so arranged that each included trees of the following varieties: Elberta, Alexander, Crosby, Stevens' Rare Ripe, and Hill's Chili. The lime-sulfur solution was used alone, and applied with a power sprayer with the relief valve set at 125 lbs.

The first spraying was done June 24th, 25th, 30th, and July 1st. The strongest concentration used was a dilution of 1–35, and this only on a few isolated trees which Mr. Ayers did not value highly. On Alexanders, Mr. Ayers noted that leaf burn was marked. He estimated that one-third of the foliage had fallen. On Elbertas, the defoliation was estimated at 50 per cent. On Crosbys, the foliage was apparently not seriously injured, and on Hill's Chili the results were about the same. Stevens' Rare Ripe showed results similar to Elberta above. Mr. Ayers records the observation that when the spray mixture reaches the axil of the leaf it is more likely to cause the leaf to fall.

On the plat sprayed with the 1–50 dilution it was estimated by partial count that an average of less than 20 per cent of the foliage was destroyed, and about 15 per cent destroyed where the 1–60 was used. In

*In all dilutions referred to in the text it is understood that a standard concentrate testing 31–34° Beaumé was used.

the 1–75 experiments Mr. Ayers further reports that not more than 10 per cent damage to the foliage of any of the trees was perceptible and the trees did not seem to be injured.

In view of the objectionable amount of foliage injury resulting from these concentrations, much weaker solutions were used for the second application which was made July 26th, and for the third, made August 13th. In these tests lime-sulfur solution was diluted from 1–100 to 1–300. Mr. Ayers reports no burning from any of these concentrations.

Experiments on peach foliage at Sodus, 1910

In one group of experiments, the spraying was done by Mr. Case's men, using a power sprayer, and in the other by the writer, using a hand pump in one instance and in the other the gas sprayer.

On one plat Swift's arsenate of lead alone was used at the rate of 2 pounds to 50 gallons, and on an adjoining plat the same amount of arsenate of lead with weak lime-sulfur solution, diluted 1–150. A week later, considerable injury had appeared on the trees sprayed with arsenate of lead alone (Fig. 68). The burned spots had somewhat more of a reddish tint than those caused by lime-sulfur solution (Fig. 65). On the plats sprayed with lime-sulfur, 1–150, with arsenate of lead, but very slight injury was apparent at this date (Fig. 69). It seemed then that the lime-sulfur for a time counteracted whatever caustic properties the arsenate of lead possessed by neutralizing whatever soluble arsenic might have been present.

It later became evident, however, that the lime-sulfur only delayed the action, for within a month or so after the application, injury began to appear quite abundantly on this plat also. This injury rather increased with time for several weeks, and was severe enough to be quite objectionable, the trees losing at least one-third of their foliage. It appeared to be the same type of injury as that caused by arsenate of lead (p. 122, Fig. 67). We naturally suspect, therefore, that the same reaction which took place immediately in the gas sprayer (p. 121) was in time induced by the action of the carbonic acid gas of the air; i. e., the calcium arsenate, which we will remember is formed when lead arsenate is mixed with lime-sulfur solution, had been gradually decomposed, forming as a result soluble arsenic. This as yet is only a theoretical explanation and the facts when known may reveal an entirely different interpretation of the phenomenon.* There seems little hope, however, that we can safely combine arsenate of lead with weak lime-sulfur solution for use on peach foliage unless some modification can be made to overcome this difficulty. If, as

*This problem was also submitted to the Department of Chemistry, together with the one reported on p. 121. Mr. Hedges reports as follows:

"The retarded injury caused by the mixing of the lead arsenate with lime-sulfur wash as compared with injury done by lead arsenate alone, was due, I think, to the calcium of the lime-sulfur uniting with some of the soluble arsenic of the lead arsenate. Then, by the action of the carbon dioxid of the air, some of the combined arsenic was made soluble after a period of about one month."

we suspect, the soluble arsenic causes the injury, it would be worth while to try the effect of the addition of lime to neutralize it. If the lime remains in the hydroxid form until after the soluble arsenic has been formed, it will probably be effective, but if applied with the spray it is probable that it will have been changed to the carbonate before it is needed. In this case, subsequent application of the lime would be necessary to prevent burning. This again is only a theory which remains for the chemist to prove or disprove.

The effect on peach foliage of precipitating lime-sulfur solution by the use of the gas sprayer has already been discussed on page 121. In brief, lime-sulfur alone, diluted 1–30, thus applied in a heavy application caused no injury whatever (Fig. 64). We all know that this concentration applied in the soluble form would cause very serious defoliation. It is, therefore, evidently true that the soluble sulfur causes the lime-sulfur injury. On the other hand, when lime-sulfur solution of the same concentration, with arsenate of lead, was applied in this way there was very serious injury. The trees were almost entirely defoliated (Fig. 63). This is doubtless arsenical injury caused by the arsenic being in some way converted to the soluble form by the series of reactions through which the preparation has passed (p. 122).

Self-boiled lime-sulfur, 10–10–50 formula, with 2 pounds arsenate of lead to 50 gallons, was used in two different orchards. We also applied this preparation combined with iron sulfate, 3 pounds to 50 gallons, as described by M. B. Waite ('10). Neither of these preparations caused any injury.

RUSSETING OF APPLES

We are constantly being met with the question, "What causes russeting of apples?" One man sprayed with bordeaux, another used lime-sulfur, while still another did not spray at all. All complain of having russeted fruit. One blames bordeaux, one lime-sulfur, and another the weather. Who is right? We are frank to admit that it is sometimes impossible from an examination of a russeted apple to tell with certainty what caused the trouble. We do know that something injured the epidermal cells of the fruit while young and that the russeted surface developed with the fruit as a consequence. The result is often very much the same in character, whether caused by weather conditions or bordeaux mixture. It differs principally in the extent of the injury. That russeting of fruit can be found on unsprayed trees does not prove that bordeaux or lime-sulfur may not in some cases cause a similar effect. It is only by noting comparatively the aggregate results that conclusions can be drawn. For example, we ('09) had on our bordeaux-sprayed plats 82 per cent. of

('09) Wallace, E. Niagara Sprayer Co. Fellowship Rep. 2:1–10. 1909.
('10) Waite, M. B. Va. Hort. Soc. Rept. 14:91–96. 1909.

russeted fruit, while on trees sprayed with lime-sulfur and arsenate of lead 3.7 per cent. were injured. Here it is evident that the difference, being so marked, was due almost entirely to the bordeaux. That year's work seemed to indicate that no injury to fruit could result from the lime-sulfur spray. During the current year, some mild russeting has occurred where lime-sulfur was used. It has also occurred quite commonly where no spray was used, so that with the data at hand it seems safe to say that lime-sulfur is rarely or never responsible for russeting.

In our experimental plats this season the percentage of russeted fruit was found by actual count to be as shown in the following table:

Table Showing Relation of Treatment to Russeting of Fruit.

Treatment	Application	Orchard	Per Cent. Russeted Fruit		
			R. I. Greening	Baldwin	Hubbardston
Bordeaux 3-3-50 with arsenate of lead	1, 2, 3, 4*	Legasee	58.2	62	.....
Unsprayed	.....	Legasee	11.2	26	.....
Heavy Grade Niagara lime-sulfur 1-30 with arsenate of lead	1, 2, 3, 4	Legasee	1.4	15	.....
Heavy Grade Niagara lime-sulfur 1-30 with arsenate of lead	1, 2, 3	Legasee	2.6	.....	.....
Heavy Grade Niagara lime-sulfur 1-30 with arsenate of lead	3, 4	Legasee	4.2	.....	.....
Clear solution lime-sulfur 1-30 with arsenate of lead.	1, 2, 3, 4	Legasee	2.1	12	.....
Home-boiled conc. lime-sulfur 1-30 with arsenate of lead	1, 2, 3, 4	Legasee	1.1	.....	.....
Bordeaux 3-3-50 with arsenate of lead	1, 2, 3	Baxter	39.7	.....	.....
Unsprayed	.....	.....	9.1	.....	6.9
Niagara lime-sulfur clear 1-30 with arsenate of lead.	1, 2, 3	Baxter	3.4	.....	1.2
Niagara lime-sulfur clear 1-30 with lead arsenate gas sprayer	1, 2, 3	Baxter	5.4	.....	1.2
Niagara lime-sulfur clear alone no lead arsenate used	1, 2, 3	Baxter	6.9	.....	.....
Lead arsenate alone	1, 2, 3	Baxter	5.0	.....	1.1
Self-boiled lime-sulfur with lead arsenate	1, 2, 3	Baxter	1.6	.....	0
Self-boiled with lead arsenate and iron sulfate	1, 2, 3	Baxter	1.4	.....	.....

*Application No. 4 was made late (in August) as an insurance against late scab infection and second brood codling moth.

TABLE SHOWING RELATION OF TREATMENT TO RUSSETING FRUIT.— Continued.

TREATMENT	Application	Orchard	PER CENT. RUSSETED FRUIT		
			R. I. Greening	Baldwin	Hubbardston
Unsprayed	.....	Case	.....	35	.....
Niagara lime-sulfur with lead arsenate	1, 2, 3, 4	Case	.....	26	.....
Niagara lime-sulfur clear 1-30 with arsenate of lead and lime	1, 2, 3, 4	Case	.....	11	.....
Niagara lime-sulfur clear 1-30 with lead arsenate and lime	2	Case	.....	14	.....
Bordeaux 3-3-50 with lead arsenate	1, 2, 3, 4	Case	.....	60	.....

We see by this table that in every case the russeting was decidedly more marked on the bordeaux-sprayed fruit than on fruit treated with lime-sulfur preparations of any kind. There was even less russeting on the latter than on the unsprayed. We cannot explain why the lime-sulfur should lessen the natural russeting or that induced by weather conditions, but in each case there was a smaller percentage of the fruit thus injured. This difference was even more pronounced in our work of last season (1909), when the russeting on lime-sulfur-sprayed fruit was 3.7 per cent, on unsprayed 29 per cent, and on bordeaux-sprayed 82 per cent.

While it may be possible that lime-sulfur under certain conditions does cause russeting of fruit it is quite evident that it did not do so in any of the cases referred to above. In August, 1910, we were shown a block of trees belonging to Mr. P. J. Teats, of Williamson, which had been sprayed late with Niagara lime-sulfur (heavy grade), diluted 1–7, and arsenate of lead. The leaves had been considerably scorched but the fruit was perfectly smooth. One would naturally expect to find russeting from lime-sulfur here if anywhere.*

REMARKS AND CONCLUSIONS

We are yet uncertain as to what extent and in what way lime-sulfur injury is influenced by weather conditions. There seemed in our experiments to be no correlation between the weather at the time of or after application and the resulting injury. It is probable that the general weather conditions of the season previous to the time of application may so influence the foliage as to make it more or less susceptible to lime-sulfur spray injury.

The method of application is a very important factor. Over-drenching is likely to cause burning of the foliage and should be avoided, at the same time care being taken to thoroughly coat all parts of the tree.

Arsenate of lead is the only arsenical that has thus far proved to be safe for use with lime-sulfur solution on apple foliage. Arsenite of lime, arsenite of soda or paris green is likely to cause serious foliage injury, while arsenate of lead decreases to some extent the caustic properties of lime-sulfur solutions. It is possible, however, that it may in some cases also cause injury after long exposure to the action of the atmosphere, or when applied with the gas sprayer. (See p. 121).

* Since the above was set in type, we have read the manuscript of a forthcoming bulletin of the Maine Agricultural Experiment Station by W. W. Bonns, and of a New York (Geneva) Experiment Station Bulletin by P. J. Parrott, in which the authors record russeting of fruit which they consider to have been caused by lime-sulfur solution. A. B. Cordley, of Oregon, in a letter reports similar fruit injury. All agree, however, that the fruit injury caused by lime-sulfur is of minor importance.

The addition of lime or the retention of the sediment in the lime-sulfur solution seemed to have very little if any effect on the amount of foliage injury caused by the spray.

Precipitation of lime-sulfur solution alone by carbon dioxid, applying it, for example, with the gas sprayer, prevents its caustic action on peach foliage when used even as strong as 1–30. Precipitation of lime-sulfur and arsenate of lead in the same way is very dangerous when used on peach foliage. There was in this case no serious burning of apple foliage treated in this way. The carbon dioxid probably liberates soluble arsenic, which seems to be responsible for the burning. It would therefore not be advisable to use a gas sprayer when lime-sulfur solution and arsenate of lead are to be combined, on peach foliage, at least.

Infection of apple leaves by the scab fungus previous to application is one of the most common causes of spray injury. The injury caused by the fungus admits the spray material to the inner tissues of the leaf more readily. Probably insect injuries sometimes play an important part in spray injury also.

There is some evidence that the foliage of healthy vigorous trees is better able to resist the caustic action of the spray material than that of weak ones. Just how far this is due to physiological effects and how far to greater injury by parasites is as yet uncertain.

Varietal susceptibility is important, at least with pears. The Duchess is much more susceptible to spray injury on the foliage than any other variety noted. With apples, no marked degree of resistance or susceptibility has been noted in any of the varieties observed by us. Scott, however, notes that the Winesap was much more resistant to spray injury than other varieties.

On peach foliage, Swift's arsenate of lead alone caused foliage injury to appear sooner than where the same amount was used with lime-sulfur solution diluted 1–150. Injury from the latter appeared, however, about a month later and the type of injury was identical with that caused by arsenate of lead alone. This indicates that this soluble arsenic was in some way at first neutralized by the lime-sulfur but later made soluble after long exposure to atmospheric agents. (See p. 122).

If russeting of apples is ever due to the lime-sulfur spray it is very rare and of minor importance. There was this season considerable russeting on unsprayed fruit due to natural causes. In our experiments, even this natural russeting was reduced by the lime-sulfur spray.

The action of lime-sulfur in causing injury differs fundamentally from that of bordeaux. Bordeaux injury may in some cases not occur for some time after the spray is applied or until the atmospheric conditions

are favorable. Lime-sulfur injury, we believe, is caused before the solution has dried on the tree. In other words, in bordeaux as applied the copper is in the insoluble (hydroxid) or harmless form and cannot cause injury until certain changes occur. In lime-sulfur solution, on the other hand, the sulfur is applied in the soluble (harmful) form which is many times more caustic than at any time after it has once dried. It is probable that all cases of delayed or prolonged occurrence of injury from lime-sulfur combined with an arsenical have been caused by the arsenic and not by the lime-sulfur.